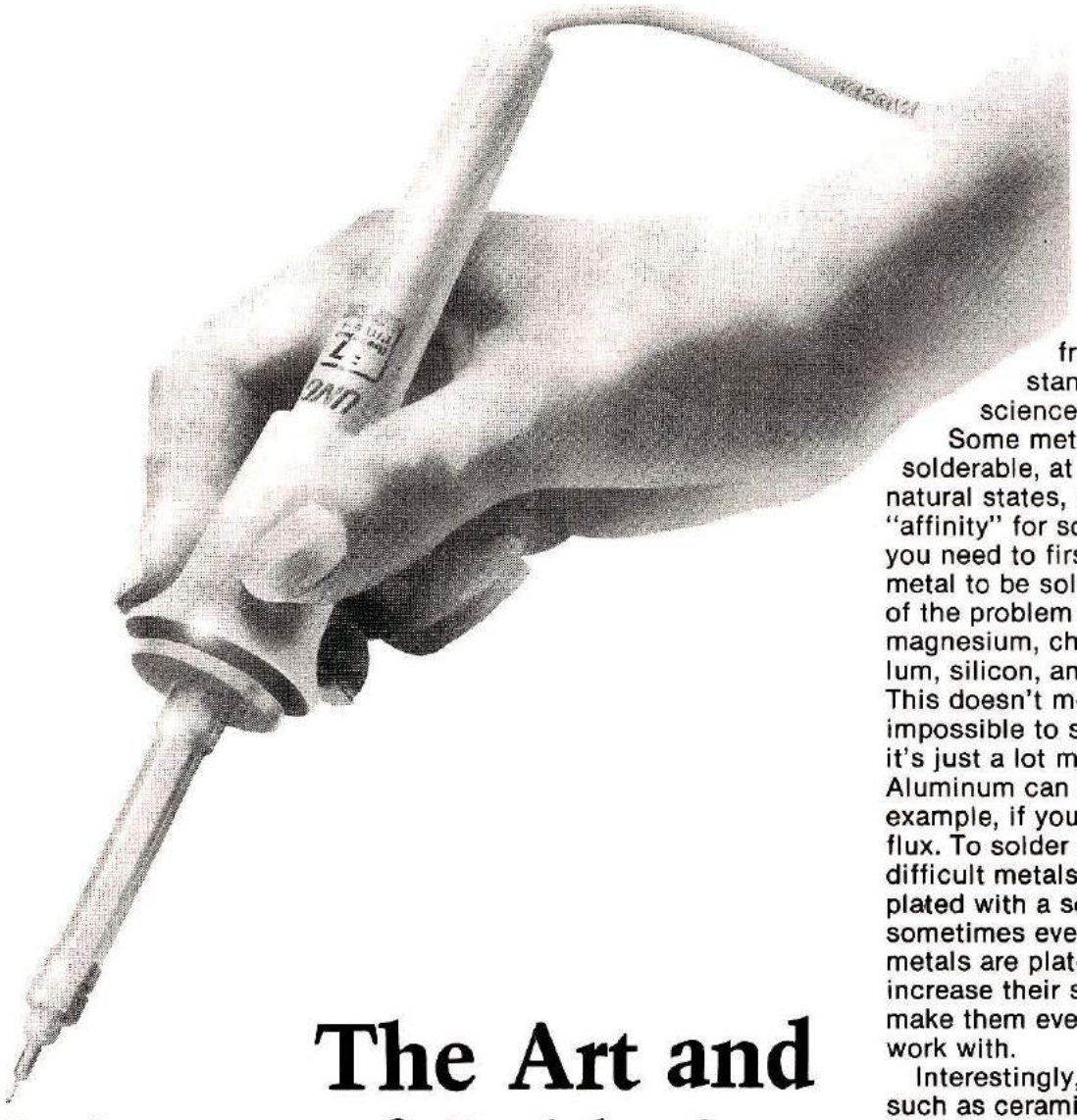


The Art and Science of Soldering

BY KARL T. THURBER, JR., W8FX/4

Learn to do it right, and save many later headaches

There really is nothing all that difficult about soldering. Still, most kits that are returned to the manufacturer, and a good number of homebrew projects that go awry, suffer from no more than poor soldering. Although "cold" connections cause most soldering problems, short circuits, flux corrosion, heat damage to components, and the like also cause grief to the builder.

Soldering is a quick, simple, and inexpensive method of joining metals together. In fact, solder is one of mankind's oldest and most widely used alloys, being used by the ancient Romans and medieval architects. Unfortunately, it is frequently misunderstood and even more frequently misused. So, before discussing how to solder properly and what equipment to use, let's first take a look at solder from a *technical* standpoint — the science of soldering.

Some metals are just not solderable, at least in their natural states, not having an "affinity" for solder. Therefore, you need to first consider the metal to be soldered — some of the problem ones being magnesium, chromium, tantalum, silicon, and aluminum. This doesn't mean that it's impossible to solder to them; it's just a lot more difficult. Aluminum can be soldered, for example, if you use a special flux. To solder most of the difficult metals, they must be plated with a solderable metal; sometimes even solderable metals are plated in order to increase their shelf-life and make them even easier to work with.

Interestingly, non-metals such as ceramics and glass can be made solderable by a process called "firing," in which powdered silver, or other metal, is mixed with a borate, heated, and applied to the non-metallic surface, resulting in its becoming coated with the solderable metal.

What is solder?

Solder is simply a tin-lead *fusible alloy* that flows at a fairly low temperature, around 370°F (187°C). The low melting temperature allows connections to be made easily with home-workshop tools — soldering irons, guns, and pencils. Sometimes, small amounts of other metals such as antimony, bismuth, or silver are added to the tin-lead alloy

to enhance the solder's characteristics or to make it suitable for some special purpose. Because of its relatively low melting point, solder is used to form a metallic union or "joint" of two metals at a temperature well below their own melting points. To do the job right, the metals must be clean and free of *all* non-metallic matter, such as grease, or oxides which form on the surfaces of most metals. These impurities form an *insulating barrier* that prevents good metal-to-metal contact; excess oxides or other "junk" on the surfaces will make good soldering very difficult, if not impossible.

Solder is usually identified by its tin-to-lead composition. If you look at a package or roll of solder, you will probably find listed either the figures 40/60, 50/50, 60/40, or 63/37. These numbers are the percentages of tin and lead, the tin percentage always being given *first*. As you will see later on, solder with a higher tin content melts at a lower temperature, which is usually desirable. Solder with more tin also costs more, because tin is an expensive metal.

Let's examine more closely just what happens when you use that soldering iron or gun. Since solder adheres by depending on a solvent or metallurgical action, the whole process breaks down if the solder itself is of poor quality, or of the wrong composition. When tin is added to lead, the melting point of the *lead* decreases along a known *composition-temperature line*. Likewise, when lead is added to tin, the melting point of the *tin* is lowered along another such composition-temperature line. The intersection of these two lines is known in the trade as the *eutectic point* and is shown graphically in **Fig. 1**. The so-called "eutectic alloy", made up of 63% tin and 37% lead, has a melting, or eutectic, temperature of 361°F (182°C). This composition is the standard for electronic purposes (being approximated by 60/40 solder), and has a very sharp, pronounced, melting point. Other solder compositions will have a flexible or *plastic* range running from the 361-degree eutectic temperature up to the melting points of either pure lead (620°F, 326°C), or pure tin (450°F, 232°C).

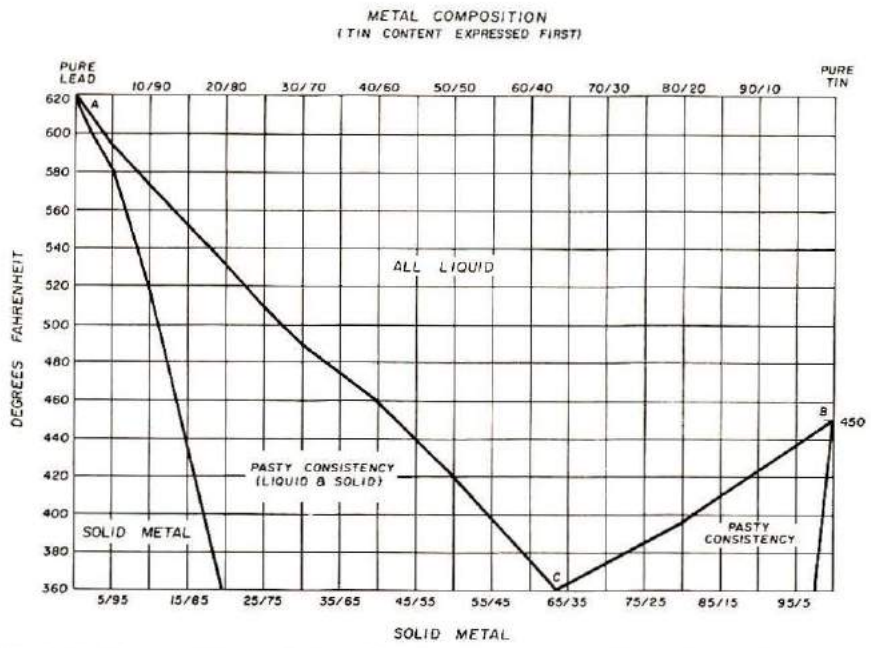


Fig. 1. As the percentage of tin and lead changes, the melting point varies along a smooth line. The lowest melting-point temperature is for a mixture of 63 per cent tin, 37 per cent lead (*information from the booklet* Solders and Soldering, *prepared by the Solder Manufacturers Committee of the Lead Industries Association*).

Rosin core solder of 60/40 composition is the most free flowing variety. The smaller diameters are particularly good for PC board work. High-quality solder is essential for good solder connections and trouble-free electronic circuits.

Another point that we haven't discussed is strength: a nice-looking solder connection does nothing for you if it won't take at least a little stress and strain. Since tin is a more active metallic "solvent" than lead, the quality of the joint is very closely related to its tin content. Taking a look at **Fig. 2**, you can see that solder with less than about 30 per cent tin content is inferior in its ability to take stress. The alloy "quality curve" reaches its peak with about 60 per cent tin alloy, which happens to closely correspond to the composition of the eutectic alloy we just described. Solders with a 63/37 or 60/40 composition are the most free-flowing kinds and are particularly good for working on delicate printed circuits.

Solder is most convenient to use in thin 16- or 18-gauge wire form; thicker solders are difficult to control in terms of quantity and usually don't flow quickly enough. Be sure to buy only the best solder, and if it causes any problems, discard it and try another brand!

How about fluxes?

Three things are necessary for good soldering: good

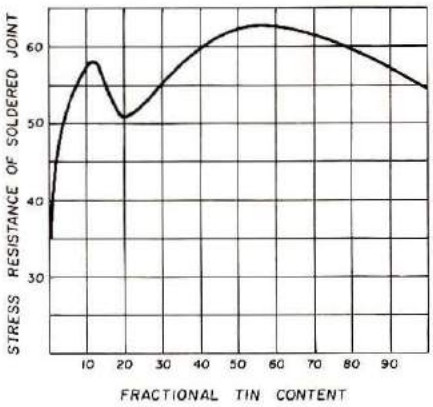


Fig. 2. The stress resistance of a soldered connection is related to the percentage of tin in the alloy, and the point of best resistance is not far from the 63/37 eutectic point shown in **Fig. 1** (*from "Solder and Soldering," by Clifford L. Barber, Research Director, Kester Solder Company, in* Popular Electronics, *March, 1973, reprinted by permission*).

solder, enough heat, and the right flux. The solvent action that takes place between metals when you solder them can't properly take place if the metals are insulated from one another by a nonmetallic barrier or film, such as that formed by an oxide. The soldering *flux* removes the oxide film (which is usually invisible to the eye) during soldering, to allow good metal-to-metal contact and the metallurgical process to take place. The action of the flux is sometimes known as *wetting* the metal; after soldering is complete, the oxides lie inert on the surface of the solder joint.

There are literally hundreds of soldering fluxes on the market. But, you will likely see three basic types: acid or chloride, organic, and resin or rosin. Rosin flux is the only kind that's usable in electronic construction and repair work. Acid and chloride-salt fluxes are very highly corrosive (since they attract moisture) and have no place in electronics! A non-corrosive, non-conductive, rosin-type flux is excellent for general-purpose electronic soldering. A special aluminum-oxide-reducing flux is also available for soldering to aluminum. Using the acid or salt type fluxes is almost sure to lead to later problems with circuitry — remember this fact, if nothing else, from this article!

For solder to properly adhere to a connection, the metal surfaces have to be free of oxides, clean, and well heated. The most effective way of reducing oxidation is the use of an oxide-reducing rosin flux, though it won't remove grease, dirt, paint, oil, dust, or other foreign matter (you do this yourself with a brush or cloth).

Solder and soldering fluxes are so closely related that the two have been combined and manufactured in a balanced combination for general purposes. The solder is fabricated so that it contains one or more *cores* of rosin flux. Since the flux-core types of solder combine both the solder and flux, two materials whose characteristics are physically and chemically very different, the solder should be used in such a manner that both are applied at the same point where the action of both is needed. This is done by placing the tip of the soldering iron *directly* against the connection to be soldered, and *simultaneously* applying the solder at the point of contact of the iron with the metal. This means that you don't let the solder run down the tip, or try to heat up the whole area first. (More on soldering techniques later.)

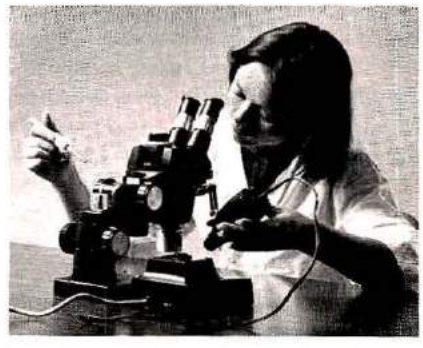
From the preceding discussion, it's pretty obvious that you don't want any acid-core solder in your toolbox; these types may have some good industrial or automotive uses, but are not what we want to use at all. Most kit manufacturers are adamant against the use of acid-core solder on their kits, often supplying just enough rosin-core solder to build the kit, hoping the kit-builder will take the hint and use the hank supplied. In fact, Heath Company's warranty clearly states that it will not cover any kit damage caused by *corrosive solder*; also, if you run into trouble with a kit wired with acid-core solder or paste flux, Heath *won't repair it*. Take heed!

Finally, watch out for solder you may find in discount stores, hardware outlets, and other places that cater to the general public. Read the label of the solder pack carefully (reject it if there is none!), to make sure that what you have isn't an acid-core type, or an excessively thick-diameter industrial version that's hard to work with, or is solder of the wrong composition (such as 40/60 type). You don't want this, either, since the melting point of 40/60 solder is many degrees higher than the 60/40 kind!

Some soldering problems

One of the biggest problems in getting good results in the soldering process is *insufficient heat*. The alloying action just won't proceed properly if there isn't adequate and uniform application of heat between the solder and the metal being soldered. Good solder joints won't happen unless the metal is hot enough to keep the solder liquid; otherwise, what results is the classic *cold solder joint*. The cure: use enough heat to do the job, *but no more*.

Another exasperating situation occurs when you try to solder a heavy piece of metal



A professional at work soldering delicate equipment. A binocular microscope is used to view the operation (*courtesy Ungar Division of Eldon Industries*).

with a cheap, under-rated soldering iron with insufficient heating capacity. The cure, obviously, is to use a big enough iron — but recognize that if you're trying to solder something really large, that it isn't really electronic work at all, but more like welding!

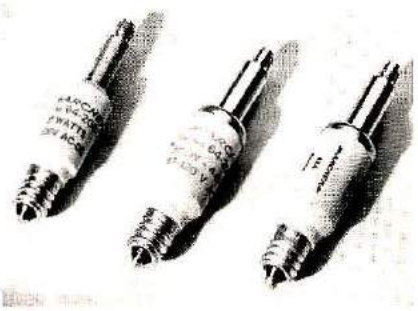
Cold-solder joints can cause enough frustrations to make the most stalwart individual curse and mutter under his breath when he tries to trouble-shoot the symptoms of this malady. These cold-solder problems tend to blend into regular electronic malfunctions, making them particularly difficult to spot. They can appear as either open, intermittent, high-resistance, or even apparently normal connections. They can trick you into suspecting other components, such as resistors, transistors, capacitors, and tubes. (A good magnifying glass and a sharp eye to check for ragged-looking, flaky, or loose connections helps).

The tools of the trade

If you are confused and perplexed by the catalog descriptions and advertisements for soldering gear (guns, irons, and accessories), you have good company. The state of the soldering art has progressed considerably over the years, along with the rest of the electronics field, and has spawned many new, and even exotic, tools and aids.

For most applications, the plain old soldering iron is still the most widely used and is quite effective, if one is chosen that is right for the job. On the other hand, too much of a good thing can cause problems, too, in soldering delicate printed-circuit boards; too much heat invites disaster in complicated electronic circuits. Obviously, the iron used and amount of heat applied must be suited to the specific application — 200- or 300-watt irons and guns shouldn't even be on your workbench if you plan on doing *electronic* soldering as opposed to general-purpose *electrical* soldering.

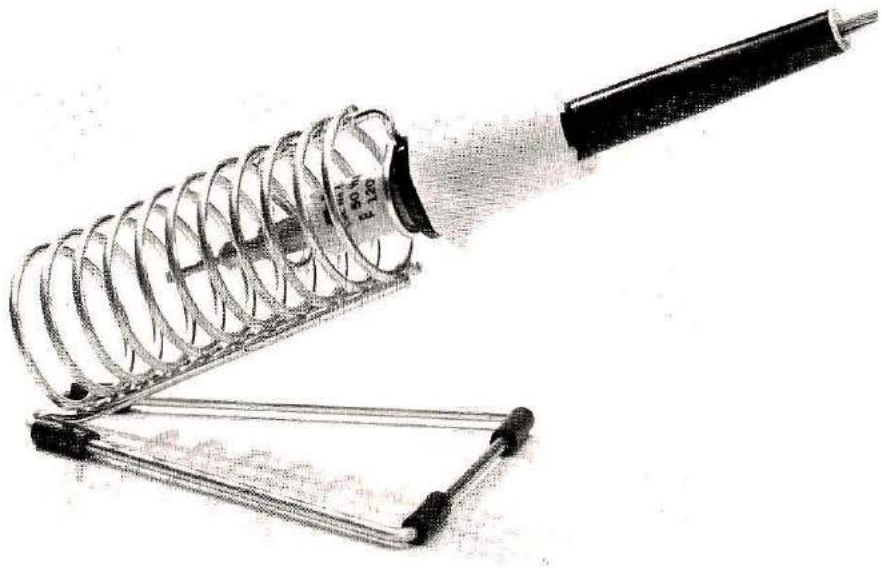
There are a large number of soldering tools on the market for both general and specialized applications, including large soldering irons, pencil irons, and guns. All of them are rated by their electrical power consumption. Due to their high efficiency, you can disregard



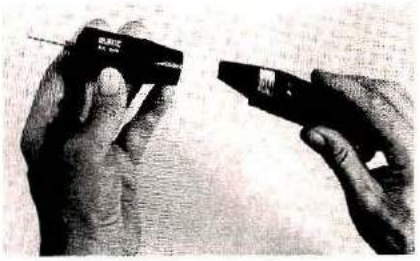
Many of the modern soldering irons have heating elements that you can remove from the handle. In addition to the easy replacement feature, it allows you to tailor the heat power to your need. Shown here are the 27, 37½, and 50 watt sizes (*courtesy Radio Shack Corporation*).

any losses and consider the wattage rating as "heat power," for practical purposes. This heat-power rating designates the tool as being for light duty (15 to 50 watts); medium duty (50 to 100 watts); or heavy duty (100 watts and over). However, the arbitrary ratings placed on the equipment by manufacturers can be tricky. For example, some very cheap "30-watt" irons have a tough time even getting solder to melt, while some "100-watt" guns will practically vaporize your connections. So you have to be aware of the ratings, but at the same time don't depend on them too much.

Both soldering irons and pencils are characteristically lightweight and compact, costing from about $2 for a "cheapie," up to $30 or more for precision, long-life units which sport special interchangeable elements, tips, and other attachments. Irons and pencils are designed for prolonged use with minimum tip deterioration, and therefore are especially good for kit-building and extensive project work. Both have a resistance element as the heat-generating device, which is (hopefully!) *electrically isolated* from the soldering tip, but *thermally coupled* to it. The tip is possibly the most important part of the unit, since the size of the tip greatly affects the



Radio Shack *Custom Design* soldering iron is shown here resting on a handy iron holder, which keep the iron conveniently located, but which prevents the hot tip from coming into contact with other materials or components (*courtesy Radio Shack Corporation*).



A miniature drill attachment for a cordless soldering iron is useful in more ways than you can imagine. It has been used extensively in the construction and repair of PC boards (*courtesy Wahl Clipper Corporation*).

initial heating and heat-recovery times. The tips are made of various types of metal, though copper is generally used. A simple, straight, copper tip with two flat faces, like a wedge, is most often used for general-purpose irons. Very slim, pointed tips are frequently used for delicate PC-board work. Many styles of tip faces are available, as can be seen by the representative sample in **Fig. 3.**

In recent years, a new type of "controlled heat" iron has become quite popular, particularly among kit-builders and repair shops. It has several different heat-power settings available to allow the solderer to select the amount of current for the range desired. With this type of iron, there is usally a separate step-down transformer, with a tapped secondary winding, housed in a small box separate from the iron.

In contrast to soldering irons and pistols, the *soldering gun* (which has a built-in transformer) is relatively heavy and bulky. However, the easy-to-grip, pistol-like design makes it very handy to use; the guns usually cost from $7 to $20 or more. The soldering *gun* has a distinct advantage over the iron: *instantaneous heating*. It has a built-in transformer which provides a high current *directly* to the tip, causing the tip to come up to full heat almost instantaneously.

The soldering *pistol* usually has about the same shape as its close cousin, the soldering gun. It's a hybrid design, with the features of both the soldering iron and gun. It combines the gun-type heating element and step-down transformer with the iron's soldering tip. It, too, heats almost instantaneously. As a general rule, soldering irons and pencils are light- and medium-duty tools; guns are for medium- to heavy-duty work, while pistols can be found in either light, medium, or heavy-duty designs. (There are probably more exceptions to this rule-of-thumb than you would care to count!)

State of the art

One of the most useful soldering tools developed in recent years is the rechargeable "cordless" soldering iron. This device allows completely portable operation without being tied to the ac mains like conventional irons. The typical cordless unit is equivalent to a 50-watt iron and has a self-contained, rechargeable battery pack that will produce anywhere from 100 to 175 solder joints per charge. The tip usually comes up to operating temperature in 5 to 8 seconds. Early rechargeable units suffered from inability to

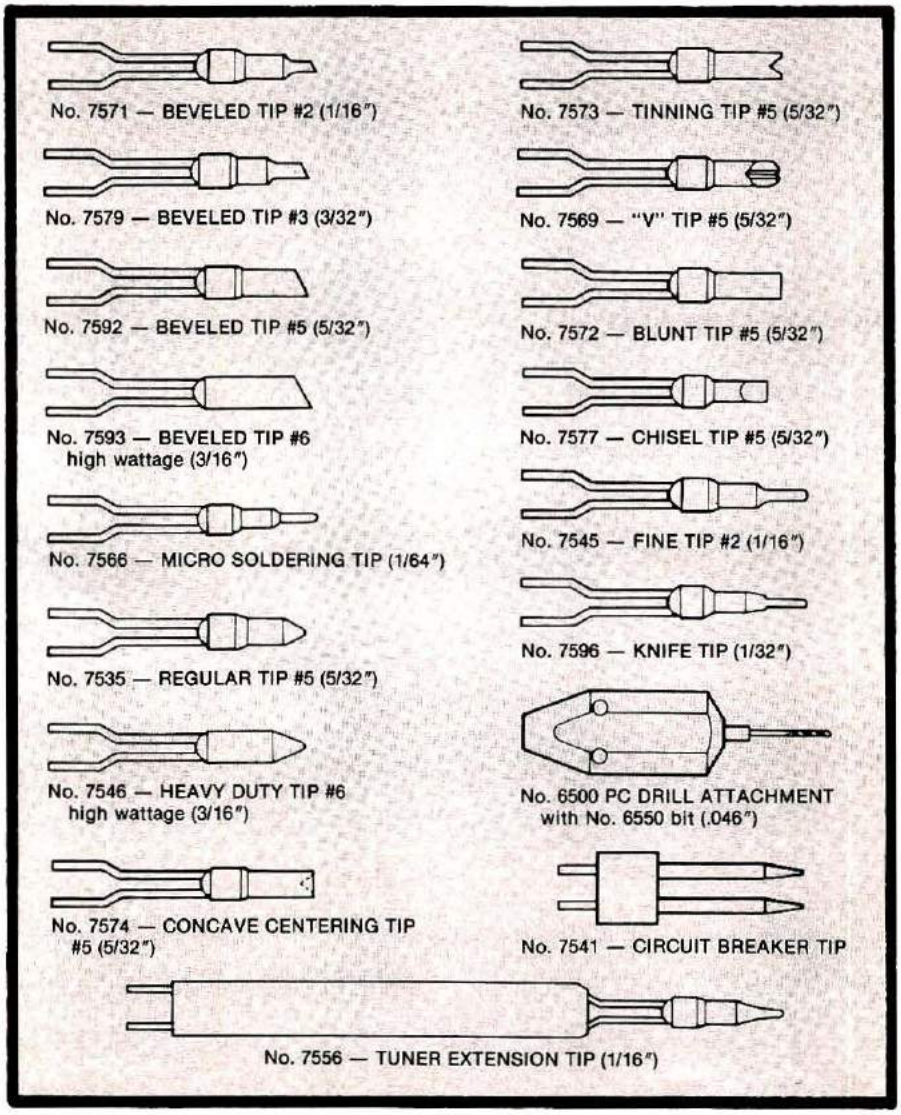

No. 7571 — BEVELED TIP #2 (1/16")
No. 7573 — TINNING TIP #5 (5/32")
No. 7579 — BEVELED TIP #3 (3/32")
No. 7569 — "V" TIP #5 (5/32")
No. 7592 — BEVELED TIP #5 (5/32")
No. 7572 — BLUNT TIP #5 (5/32")
No. 7593 — BEVELED TIP #6 high wattage (3/16")
No. 7577 — CHISEL TIP #5 (5/32")
No. 7566 — MICRO SOLDERING TIP (1/64")
No. 7545 — FINE TIP #2 (1/16")
No. 7535 — REGULAR TIP #5 (5/32")
No. 7596 — KNIFE TIP (1/32")
No. 7546 — HEAVY DUTY TIP #6 high wattage (3/16")
No. 6500 PC DRILL ATTACHMENT with No. 6550 bit (.046")
No. 7574 — CONCAVE CENTERING TIP #5 (5/32")
No. 7541 — CIRCUIT BREAKER TIP
No. 7556 — TUNER EXTENSION TIP (1/16")

Fig. 3. Some of the many styles of tips available for general purpose or special applications. These are for Wahl equipment; most manufacturers offer several tip sizes and shapes (*courtesy Wahl Clipper Corporation*).

The new generation of cordless soldering irons provides great freedom from the ac cord that often hampered movement in delicate soldering operations. The very small tips available make the unit especially useful for densely packed construction projects (*courtesy Wahl Clipper Corporation*).

be used *continuously*, making them unsuitable for extended kit-building or project work; their charges became depleted very rapidly. However, most present units on the market have overcome this problem, and the batteries can be brought up to a full charge again in less than an hour after completely discharging. Some of the more advanced models allow for continuous trickle-charging when not in use and have LED indicators which tell when charging is complete. Many of these units have provisions for interchangeable tips and other accessories.

Wahl Clipper Corporation has a novel drill attachment for their *Iso-Tip* rechargeable iron; it replaces the tip of the iron, and obtains power from the unit's battery pack. Accessory burrs, abrasive wheels, and discs are also available which allow the drill to carve, shape, form, and rout on wood, plastic, leather, and other materials.

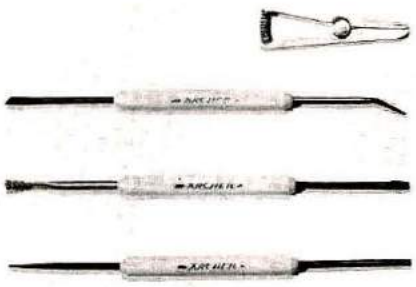
If you're starting from scratch with no soldering gear, you may be interested in Heath Company's controlled-heat soldering iron kit, model GH-17A. It is unique in that it combines the chicken and the egg into one package, so to speak: you can actually use the kit to build *itself* by following the special instructions that Heath provides! It's easy to assemble in approximately an hour. Some of its good features include selectable 20, 22, or 24 watt heat positions, a hood to shield the iron from inadvertently touching other components, and a special holding bracket that brings your work to the iron. It comes with a small chisel tip, especially good for solid-state work; other tips are available. I built one of the units and find that it works well for all but the heaviest electrical work.

Another new product is the "hybrid" cordless soldering gun which has double or triple the capacity of regular rechargeable irons. Wahl manufactures a gun that will produce from 350 to 400 electronic joints per charge, and which has an automatic solder-feed system that is activated by the trigger. Sixteen interchangeable tips are available making this gun useful for delicate micro-circuit applications, up to production electrical soldering.

We've looked at the hardware — now let's look at the *software*: the human element in soldering. Have you ever thought about just what goes into making a good electrical connection? It doesn't take much time to practice and learn good soldering techniques and habits, nor does good soldering require expensive tools. And, if you stick to a few rules, you'll consistently produce good, permanent, soldered connections, whether it be for purposes of kit-building or repair work. (Incidentally, the Romans made watertight lead pipes, medieval workmen soldered stained-glass windows in cathedrals, and Victorian tinsmiths made tin roofs watertight — and many of these soldering jobs are intact today!)

If there's a basic rule about soldering, — referring to both the *connection and tools*, it is: Keep it *clean*! The tip itself must be clean, with its surface lightly coated with solder to prevent its deterioration from oxidation. This is called *tinning*, and helps in the transfer of heat from the tip to the connection to be soldered. You should clean and tin the tip of the soldering tool with solder after its purchase, *before* you try to use it in actual soldering operations. Wear on the tip is *not* due to

Cordless soldering guns, such as the Wahl unit shown here, can provide up to three times the "heat power" of regular cordless irons. This type of gun has a plug-in type of charger which can completely recharge a dead battery overnight. It also has a solder feed, and a choice of 16 different accessory tips (*courtesy Wahl Clipper Corporation*).



Some basic soldering accessories: a heatsink for protecting sensitive components, wire brush/scraper, and slotted probes (*courtesy Radio Shack Corporation*).

erosion or to the flux; rather, it's due to the effect of the molten solder on it. Some manufacturers coat their copper tips with iron; this makes them less efficient in heat transfer, though it increases their lifetime.

In addition to a clean tip, the terminals and components to be joined must be clean; the old saw, "well cleaned is already half soldered," is certainly true. You can easily clean a dirty lug or component lead with a special steel-hair brush designed for the purpose, or you can use a small strip of emery cloth or a file to remove stubborn foreign particles. The iron or gun should be hot enough to allow soldering to proceed quickly, but not so hot that the solder "burns" and the free flux on the tip develops into black flakes; if your iron or gun is adjustable, try different settings to determine which are the best to use. The tip should be cleaned frequently during prolonged sessions. This can easily be done by lightly running a common washcloth or rag across its surface, particularly when it is only moderately hot. Don't let the cloth remain in contact with the tip for any extended period, or it will char and possibly catch fire. Specially-treated cleaning pads and sponges offered by several manufacturers can also be used.

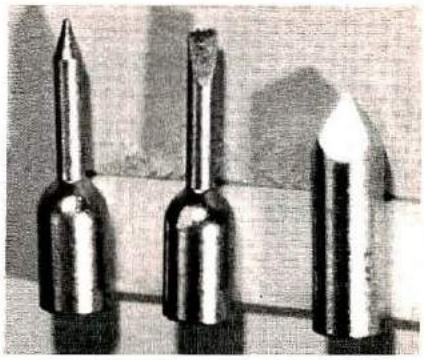
If the tip becomes pitted, don't be too concerned; this is a result of normal soldering action. The iron's (copper) tip can be lightly filed to remove the black spots of oxidation, and then retinned. Also, if your iron has a detachable tip (most do), you should periodically dismantle it from the heating element, or you may find that it has permanently bonded itself in place! Some people like to store the heating element and handle with the tip removed, though this isn't by any means necessary.

Once the components and terminals you want to solder are clean, they should be connected together to form *both* a good mechanical and electrical joint *before* soldering. Do not rely on the solder to hold the works together! If parts fit too loosely, a weak joint will be the result, or even no joint at all if the gap is too wide for the solder to bridge.

You should place a *heatsink* on the leads of particularly delicate or heat-sensitive components such as transistors, integrated circuits, small capacitors, diodes, and the like, to divert heat from them. The heatsink can be a commercially-available device, pliers, or even a paper clip. In any case, the heatsink should be placed as close to the component as possible.

While on the subject of heatsinking, I'll bring up another closely-related matter: many components, such as integrated circuits and field-effect transistors, can be destroyed by static or stray electricity which comes in contact with them. For this reason, many of these devices are furnished with the leads jumpered or shorted together with a ring of fine wire to prevent static electricity build-up from damaging them. Since the tip of the soldering tool is a conductor, be sure to leave the short on the leads of these devices until soldering is complete and you're ready to apply power (but don't forget that they're jumpered!).

If you're going to do a lot of work on PC boards or other miniature equipment, a magnifier can be a great tool to inspect the completed connection. This one is 4x magnification, and illumination is powered by two AA cells (*courtesy Radio Shack Corporation*).



Some of the most common tip shapes for electronic work are included in this selection from Radio Shack. These units, for light, medium, and heavy-duty applications, can be obtained in either copper-alloy or long-life iron-clad styles (*courtesy Radio Shack Corporation*).

Now, to solder the connection . . . apply the tip to the connection and almost simultaneously apply the solder to the junction between the tip and the connection. A small amount of solder should flow between the iron tip and the wire or component, which aids in transferring heat to the connection. The connection then becomes hot enough for the solder to flow onto it, forming a solder fillet between all of the parts. Apply just enough to fill the gaps, and no more. Excess solder will flow into places where it is not needed, or where it can cause a short circuit. No additional flux is needed, because the flux core in the solder will melt and flow over the connection just before the solder does. Any small amount of oxide that has formed since you cleaned the connection will float to the top of the solder, out of harm's way. The time for the entire operation should be very short

A desoldering vacuum bulb is useful for removing solder from a connection without splattering. The treated sponge will help to keep the iron's tip clean and free of excess solder and flux (*courtesy Radio Shack Corporation*).

— it can be done in less time than it takes you to read this sentence, especially for small components.

To complete the process, remove the solder first, then the tip, and be very careful not to allow the connection to move while the solder is solidifying; resist the temptation to prematurely "test" the connection — you'll set up tiny fractures within the joint if you do, thereby weakening it.

Now, what does a good solder connection look like? It is one where the solder has uniformly flowed over all the surfaces to be connected, following their contours. The connection should appear bright and smooth, all wires in the connection appearing well-soldered. However, if the connection is *rough* or *flaky-looking* — or if the solder has formed into little round balls, *do it over*! If allowed to cool undisturbed, the solder should solidify nicely into a permanent connection. Don't apply water to speed up the process of chilling. It's best not to use water to clean any solder joint that uses a rosin flux, due to the possibility of a corrosive chemical reaction. The rosin residues can be left in place with no danger of corrosion, or they can be removed with a rag or a brush and special solvents.

That's really all there is to good soldering! With a little practice and keeping these rules in mind, you can do a professional soldering job every time.

There are a number of soldering accessories and gadgets that can make kit building, home-brewing, and general repair work a great deal easier. Let's take a look at some of them. Assuming you are fairly well-equipped with some basic tools, such as needle-nose pliers, an assortment of screwdrivers, knives, wire strippers, and the like — as well as a soldering iron or gun suited to your taste and the job at hand — probably the most important soldering accessories would be a set of brushes, scrapers, and probes as shown in the photo. A heat-sink to protect delicate components is a must, although it need not be a commercially manufactured item. It may be a paper clip or home-built clamp of some sort; even your pliers can serve to grip the components that need protection from excessive heat.

Something to clean up the iron and keep its tip shiny is also a must; this can be a sponge, rag or even brown paper towels. A good 3x to 4x illuminating magnifier is also handy for examining connections, working with small components, and doing delicate PC-board repair work.

Solder-removing wicks are used in repairing PC boards or salvaging components. To use them, heat the soldered connection with an iron, and apply the tip of the metal wick. Solder is pulled up the wick, away from the component. After the tip has cooled, a section is cut off, exposing fresh wick ready for the next application (*courtesy Radio Shack Corporation*).

A combination iron holder and cleaning sponge keeps the iron in a safe place and makes cleaning the tip a matter of seconds (*courtesy Ungar Division of Eldon Industries*).

If you do a good deal of repair work, a desoldering vacuum bulb is very helpful in removing solder from fragile PC boards without splattering and damaging nearby components. A simple vacuum bulb works well, although fancier devices are available from several manufacturers. Radio Shack makes a unique gadget called a *Solder-Up*, which is a specially designed solder-removing wick used in conjunction with a soldering iron or gun to repair or revise circuits.

Finally, anyone who has had the unfortunate experience of having a hot soldering iron inadvertently come in contact with a component or cabinet, thereby causing heat damage, will want to use an iron holder to keep the iron in a safe place. Some of the fancier iron holders even have built-in sponges for tip cleaning.

A final word

When building that kit, don't overlook the soldering hints packed inside most major manufacturer's kits. They're interested in seeing that you know how to solder properly, because the success of the kit depends largely on the quality of the wiring and soldering job. Take time to read them! Happy soldering. **HRH**